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(WP-200307)

Oily Sludge Biodetoxification

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ACRONYMS AND ABBREVIATIONS

BOD	biological demand
BOD_5	5-day biochemical oxygen demand
BOWTS	bilge oily wastewater treatment system
BQL	below quantitative limit
COD	chemical oxygen demand
COTS	commercial off-the-shelf
dem/val	demonstrate and validate
DO	dissolved oxygen
DoD	U.S. Department of Defense
ESTCP	Environmental Security Technology Certification Program
F/M	food to microorganism (ratio)
FNU	formazin nephelometric units
FOG	floatable oil and grease
GC	gas chromatography
GC/MS	gas chromatography mass spectroscopy
MBAS	methylene blue active substance
MLSS	mixed liquor suspended solids
MLVSS	mixed liquor volatile suspended solids
NAVFAC ESC	Naval Facilities Command Engineering Service Center
NESDI	Navy Environmental Sustainability Development to Integration
NAVSTA	Naval Station
NT	not tested
O&M	operation and maintenance
OSHA	Occupational Safety and Health Administration
OWPP	Oily Wastewater Pretreatment Plant
OWS	oil water separator
PCB	polychlorinated biphenyl
P&ID	piping and instrumentation drawing
ppm	parts per million
PQL	practical quantitation limit
PWC	Public Works Center
SBR	sequencing batch reactor
SCAAP	Scranton Army Ammunition Plant
STLC	soluble threshold limit concentration
SVOC	semivolatile organic compound

TCLP	toxicity characteristic leaching procedure
TOC	total organic carbon
TPH	total petroleum hydrocarbons
TRPH	total recoverable petroleum hydrocarbons
TSS	total suspended solids
TTLC	total threshold limit concentration
TTO	total toxic organics
USEPA	U.S. Environmental Protection Agency
WRI	Wastewater Resources Incorporated
VOC	volatile organic compound
VSS	volatile suspended solids

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1.0 EXECUTIVE SUMMARY

1.1 BACKGROUND

The Scranton Army Ammunition Plant (SCAAP) in Scranton, PA, is one of the few industrial facilities capable of forging large caliber projectiles used by the military. To keep the hot (2300°F) freshly forged projectiles from sticking to the forge, a mineral oil based lubricant that has graphite suspended in it is used to lubricate the forge. The spent forging oil along with cooling water collects in trenches under the forges and is sent to an oil water separator (OWS), and the recovered sludge is landfilled. However, the OWS functioned poorly and the concentration of oil in the discharge water often exceeded the permitted limit. During the course of the project, SCAAP installed a skimmer that captures much of the oil, which is recycled. However, even after skimming, the concentration of oil in the water exceeds the discharge limit permitted by the Scranton Sewer Authority.

In addition to Scranton, treatment plants, wash racks, fuel depots, industrial operations, and maintenance facilities at U.S. Department of Defense (DoD) activities annually generate millions of gallons of wastewater contaminated with thousands of tons of oily sludge. Collecting and disposing non-recyclable oily sludge is increasingly costly and time consuming. In the Navy, the yearly operation and maintenance (O&M) costs associated with OWSs and bilge oily wastewater treatment system (BOWTS) units are estimated to be $24 million, and the Army estimates that the cost for disposing of oily sludge generated at wash racks alone is $150,000 per base. In the civilian sector, the U.S. Environmental Protection Agency (USEPA) estimates that oily sludge disposal costs $2 billion per year. As an alternative to the current practice (landfill disposal), which is increasingly costly and restricted, on-site bioremediation offers attractive cost savings and eliminates long-term liability associated with landfill disposal.

Since oily waste is composed of refined petroleum hydrocarbons, most of which are biodegradable, on-site treatment of oily waste is technically feasible and has been confirmed in lab and pilot-scale tests. Most importantly, bacteria capable of degrading oily waste are already present in the waste; thus one of the primary requirements for successful treatment is to create conditions that optimize the growth and activity of the indigenous hydrocarbon-degrading bacteria. The most direct approach, which was used at SCAAP, is simply a well-mixed tank or sequencing batch reactor (SBR) into which oily waste (the primary food source) is fed. To ensure that the water-insoluble oil is easily accessible to the bacteria, it is mechanically emulsified and the reactor is supplemented with inorganic (nitrogen, phosphorous) and organic (vitamins and amino acids) nutrients which make it easier for the bacteria to grow. The addition of the organic nutrients also supports a more metabolically diverse population of hydrocarbon-degrading bacteria. To further promote growth, a near neutral pH is maintained and an aeration system provides oxygen and helps keep the SBR mixed.

Ideally, oily waste should be burned or re-refined; however, the physical chemical characteristics of this material are not compatible with currently available reuse technologies. Thus, DoD and the civilian sector are faced with recurrent and escalating costs for land-filling oily waste, which is in addition to the cost of removing it from the waste stream. Furthermore, DoD remains liable for the material once it is landfilled. Since on-site biological treatment does not require separation prior to treatment, these costs (which can be considerable) are reduced if not

eliminated and once the waste is degraded, it is no longer a liability. Compared to the recurrent cost of land filling, biological treatment is cost effective and the payback period can be as short as 1 year.

1.2 OBJECTIVES OF THE DEMONSTRATION

The objective of the project was to demonstrate and validate (dem/val) an innovative application of bioreactors for the on-site treatment of oily sludge generated at DoD activities. More specifically, it was shown that:

- Reactor was easily assembled on site using commercial components.
- Operation was optimized to treat the oily sludge.
- Design, cost, and performance data were developed.

The two primary quantitative performance objectives, which were both met, were: (1) the design and operation of the reactor would permit the oily waste to be degraded within design time to or below the discharge limits (see Table 1); and (2) the use of the reactor would reduce costs and the payback compared to the current practice of ~3 years.

1.3 TECHNOLOGY DESCRIPTION

The oily sludge biodetoxification system consists of a bioreactor tank, receiving or holding tank, pH controller, aeration and mixing system, ultra-filtration unit, and volatile organic compound (VOC) filters. Air and nutrients (fertilizer) are fed into the bioreactor tank where organisms already present in the sludge degrade the oily sludge, leaving only biomass, carbon dioxide, and clean water for recycling or discharge.

1.4 DEMONSTRATION RESULTS

The initial performance as indicated by the concentration of oil in the treated water met the discharge requirements. However, unexpected problems associated with the physical properties of the oily sludge and the scale of the system required that the system be modified, and SCAAP also reduced the volume of wastewater but not the volume of oil. The treatment system was modified to accommodate these problems, and subsequent testing demonstrated that the concentration of residual oil in the wastewater was reduced to the permitted discharge limits and a simple carbon canister (rather than the originally proposed biofilter) was sufficient to remove VOCs in the SBR exhaust air.

1.5 IMPLEMENTATION ISSUES

During the course of the project, three implementation issues arose: (1) SCAAP reduced the volume of cooling water which increased the concentration of oil beyond the design treatment capacity. This was addressed by installing a skimmer to recover the oil, which is purchased by a recycler. (2) Oil pooled on the surface of the reactor, which limited bacterial accessibility and created impossibly long treatment times. (3) Pooled oil congealed on the surface and sunk to the bottom of the reactor where it accumulated. The last two problems were solved by installing a weir at the surface of the SBR that collected the pooled oil before it could congeal. This oil and

water were recirculated through a centrifugal pump, which kept the oil mechanically emulsified and readily available to the bacteria. Concurrently, it was recognized that the aeration system was not adequate and the new air headers were fabricated and installed. These modifications enhanced mixing, which improved degradation and reduced the potential for the oil to congeal and accumulate on the bottom of the SBR. Shortly after the project was completed, SCAAP substituted a water-based lubricant for the previously used mineral oil lubricant that has proven to be biodegradable, and they replaced the tube filter with a membrane filter that has enabled them to use all of the treated wastewater for plant cooling.

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2.0 INTRODUCTION

2.1 BACKGROUND

Annually, DoD facilities (e.g., industrial waste treatment plants, wash racks, fuel depots, industrial operations, and maintenance facilities) generate millions of gallons of wastewater contaminated with thousands of tons of oily sludge. Since much of this waste cannot be recycled or burned, the oily sludge is drummed and landfilled, which is costly and time consuming. Based on the Naval Facilities Command Engineering Service Center (NAVFAC ESC) survey, the cost to the Navy alone for handling and disposing of fuel tank bottoms and sludge produced by BOWTS is in excess of $6.5 million per year. As an alternative to the current practice (landfill disposal), which is increasingly costly and restricted, on-site bioremediation offers attractive cost savings and eliminates long-term liability associated with landfill disposal.

One of the few industrial facilities that can forge large caliber projectiles used by the military is SCAAP in Scranton, PA. To keep the hot (2300°F) freshly forged projectiles from sticking to the forge, the forge is lubricated with a mineral oil based lubricant infused with graphite. The spent lubricant along with cooling water collects in trenches under the forges. In the past the oily wastewater flowed into sumps from which it was sent to an OWS and the recovered sludge was landfilled. However, the OWS functioned poorly which caused the concentration of oil in the discharge water to exceed the permitted limit and recurring disposal costs continued to increase.

Since oily waste is derived from refined petroleum hydrocarbons, most of which are biodegradable, on-site treatment of this waste is technically feasible and has been confirmed in lab and pilot tests. However, there has been little or no documented full-scale testing of this approach, which was the objective of this project. Most importantly, bacteria capable of degrading oily waste are already present in the waste; thus the primary requirement is to create conditions that optimize the growth of the desired bacteria. The most direct approach, which was used at SCAAP, is simply a well-mixed tank into which oily waste (the primary food source) is fed. To ensure that the water-insoluble oil is easily accessible to the bacteria, a centrifugal pump is used to mix the tank and mechanically emulsify the oil. Bacteria rapidly colonize and degraded the emulsified oil droplets. In addition to nitrogen and phosphorous, which are absolutely required, bacterial growth and diversity is enhanced by supplementing the reactor with vitamins and amino acids. A pH controller is used to maintain a near neutral pH and an aeration system provides oxygen and helps keep the SBR mixed.

Ideally, oily waste should be burned or re-refined; however, the physical chemical properties of this material are not compatible with current technologies. Thus, DoD and the civilian sector are faced with recurrent and escalating costs for land-filling oily waste, which is in addition to the cost of removing it from the wastewater. In addition, DoD remains liable for the material once it is landfilled. Since on-site biological treatment does not require separation prior to treatment, these costs (which can be considerable) are reduced if not eliminated and once the waste is degraded, it is no longer a liability. Compared to the recurrent cost of land filling, biological treatment is cost effective and the payback period can be as short as 1 year.

2.2 OBJECTIVE OF THE DEMONSTRATION

The objective of the project was to dem/val an innovative application of bioreactors for the on-site treatment of oily sludge generated at SCAAP. The two primary quantitative performance objectives, which were both met, were: (1) the design and operation of the reactor would permit the oily waste to be degraded within design time to or below discharge limit, and (2) the use of the reactor would reduce costs and the payback compared to the current practice of less than 2 years. In addition, the project demonstrated that:

- Treatment system assembled on-site using commercial components
- Operation optimized to treat SCAAP oily wastewater
- Design, cost, and performance data developed.

Although it was not anticipated, changes that SCAAP made in how they manage their wastewater after the system was designed and installed were easily accommodated by on-site modification of the SBR. Coincidently, the successful outcome supports the robustness of this approach to the management of oily wastewater.

The long-term objective is to facilitate the use of biological reactors at DoD installations. To facilitate meeting this objective, a patent awarded to the Navy, which covers this application, has been licensed by a vendor (Wastewater Resources Incorporated [WRI], Scottsdale, AZ). This licensing agreement should ease the implementation of this technology, which has been demonstrated to reduce the cost of oily wastewater disposal and the inherent liability associated with landfilling.

2.3 REGULATORY DRIVERS

Regulatory drivers include Resource Conservation and Recovery Act (42 USC 6901) and Executive Order 12856 (Federal Compliance with the Right-to-Know Laws and Pollution Prevention Requirements).

The proposed project addresses the treatment of oily sludge that has been identified as a high priority by DoD mandates (Navy: 2.II.01.q Control/Treat Industrial Wastewater Discharge and Army: A(2.2.e) Improve Oil and Grease Removal/Treatment Technologies for Contaminated Wastewaters and Sludges/Soils).

3.0 DEMONSTRATION TECHNOLOGY

Industrial facilities commonly use an OWS to remove oil from their oily wastewater. If the properties of the recovered oil permit, it is sold to utilities or other certified users, which use it for fuel, or in some cases it may be re-refined. However, the physical chemical properties and the presence of other chemicals (e.g., surfactants and metals) preclude any type of recycling, and the oily sludge is placed in drums and landfilled. In addition, OWSs often require extensive maintenance, which, if it not performed on a regular basis, leave oil in the wastewater at concentrations that exceed permitted limits. Because costs continue to increase and landfill disposal is increasingly restrictive and remains a long-term liability, generators are interested in cost effective on-site treatment that will meet regulatory requirements.

Since oily sludge consists of petroleum-derived hydrocarbons and most refined hydrocarbons, including the SCAAP forging lubricant (which, even though it has undergone extensive thermal degradation is biodegradable), biological treatment is a promising alternative to the current practice. Furthermore, when compared to other treatment technologies (e.g., steam reforming), biological treatment is considerably more cost effective and biological degradation is more complete, which reducing handling and ultimately eliminating the long-term liability associated with landfill disposal.

3.1 TECHNOLOGY DESCRIPTION

Biological treatment is increasingly used to treat a wide variety of organic-rich waste streams. The most common and oldest application is sewage treatment; however, food processors, feedlots, the pulp and paper industry, oil refineries, and the automotive industry often use dedicated on-site treatment facilities to treat the organic waste that they generate. One of the advantages of on-site treatment is a reduction in sewage charges associated with high biological demand (BOD) waste along with reduced handling and disposal costs. In addition, higher water and energy costs are driving the development of technologies that make it possible to reclaim the treated water and capture some of the residual energy in the waste.

In most applications, biological treatment systems are designed to promote the growth of naturally occurring bacteria adapted to grow on and degrade the organic compounds in the waste stream. This approach as opposed to the use of engineered bacteria has the advantage that a very diverse and robust bacterial population resistant to system upsets is rapidly established and easily maintained. The basic requirements are that the system be well mixed, maintain a near neutral pH, and for most applications use an aeration system to keep the system aerobic and mixed. However, to reduce the amount of residual biomass and to generate methane, which may be captured and used as fuel, some waste streams are treated in anaerobic digesters. In general, anaerobic treatment is slower than aerobic processes and the longer residence time means that the volumetric capacity of the anaerobic system is larger than a comparable aerobic system. In either case industrial waste has to be supplemented with nitrogen and phosphorus, which are essential, and low concentrations of vitamins and amino acids, which promote more rapid and diverse bacterial growth. In recent years, technological enhancements, e.g., trickling filters, rotating bio-contactors, membrane reactors, and activated sludge systems have been developed to maximize bacterial contact with the waste and reduce processing time. However, for most

industrial wastes, a stirred tank in which waste is treated in batches or in continuous flow is often adequate.

The most common tank configuration is the SBR, which is operated in batch mode (Figure 1). The operating sequence is fill (charge with fresh wastewater), react (treat the wastewater), settle (allow the biomass and other particulates to settle), and decant (remove the treated wastewater). The advantage of this approach is that the settled biomass harbors a fresh bacterial inoculum that is ready to go when the SBR is filled with fresh wastewater. As a result, degradation of the waste (oil at SCAAP) begins as soon as the fresh wastewater is introduced. Another advantage of an SBR is that the SBR functions as a clarifier during the settle phase. At Scranton, a tube filter is used to remove particulates and bacteria that failed to settle. Periodically, excess biomass and associated sludge that accumulates in the SBR are wasted. The amount of biomass that is wasted depends on the amount of biomass that is required for effective waste degradation and has to be determined for each application.

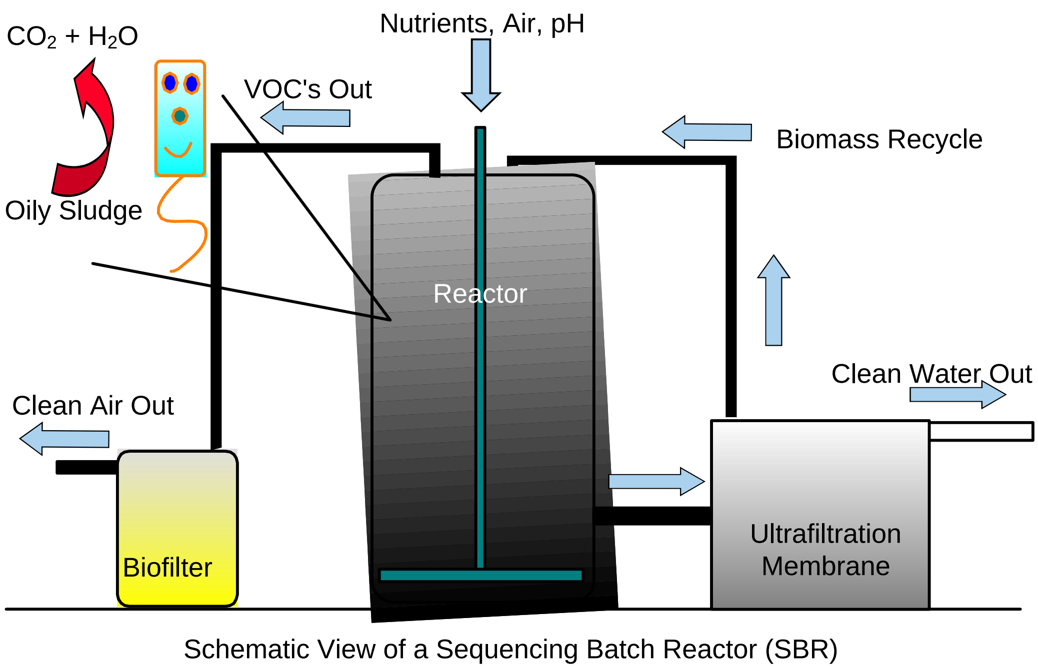

Figure 1. A schematic illustration of an SBR and the principal subsystems. During the react cycle, oily sludge is degraded and the bacterial population increases. Bacteria are captured by the microfilter and recycled to maintain a robust bacterial population. Bacteria in the biofilter capture and degrade VOCs in air vented from the SBR.

Since biological treatment will degrade more than 90% of suspended and dissolved organic compounds, it is the most cost effective treatment available for organic waste. However, excessive concentrations of heavy metals, some organic compounds, e.g., chlorinated solvents, high salinity, extreme pH or temperature will hinder and in some cases poison biological treatment systems. Fortunately, these effects are usually transient and systems rapidly recover when normal conditions are restored. Also, some organic pollutants (e.g., polychlorinated

biphenyls [PCBs]) are either resistant to biodegradation or the rate of biodegradation is so slow that biological treatment is not currently practical.

The production of volatile compounds during biodegradation or their presence in the waste stream may result in air emissions. However, these compounds can be captured and degraded by passing exhaust air from the SBR through biofilters, closed containers (usually cylindrical) filled with a mixture of inert filler (to maintain porosity) and compost (supplemented with nitrogen and phosphorous), which provide a matrix that supports bacterial growth. Bacteria growing on the compost have been shown to capture and degrade volatile hydrocarbons and some inorganic compounds, (primarily hydrogen sulfide and ammonia). Alternatively, if the concentration of VOCs in the exhaust air is low, they can be removed with activated carbon.

The end product of biological treatment in the SBR is primarily biomass, i.e., dead bacteria and cell remnants, carbon dioxide, and at SCCAP graphite that has been scrubbed of oily waste by the bacteria. Unless the concentration of metals exceeds allowable limits, the residual biomass is usually nontoxic and nonhazardous and can be captured in a filter press, landfarmed, landfilled, or composted.

With support from the Navy Environmental Sustainability Development to Integration (NESDI or YO817) program, the NAVFAC ESC, Port Hueneme, CA, conducted bench and pilot-scale tests that demonstrated the potential for bioremediating oily sludge generated at industrial facilities operated by the Navy. A critical result of this work was the demonstration that bacteria already present in and adapted to oily sludge from a variety of sources are easily stimulated to degrade hydrocarbons in the sludge within 2 weeks to less than 100 parts per million (ppm) (Figure 2). In addition, the concentrations of heavy metals (primarily zinc and copper) and total suspended solids in treated wastewater from these sources and residual biosolids were shown to be within discharge limits.

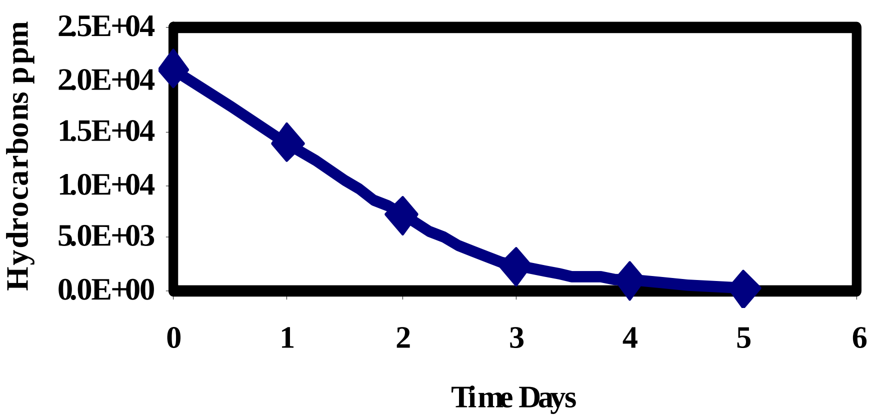

Figure 2. Oily waste degradation in the Naval Station (NAVSTA) Pearl Harbor, HI, SBR.

Because of the high disposal costs for oily sludge in Hawaii, the Public Works Center (PWC) Pearl Harbor collaborated with NAVFAC ESC to install a 10,000 gal SBR that can treat 1000 to 2000 gal of oily sludge per month (Figure 3). To achieve the high bacterial densities essential

for rapid biodegradation and eliminate the need for a clarifier, the system uses microfilters to capture and concentrate bacteria and particulates that have not settled in the supernatant. The use of concentrated biomass increases the throughput without having to increase the volume of the SBR, and the oily waste undergoes rapid degradation (currently 4 to 5 days). A unique aspect of this project is that the biomass, which accumulates in the reactor, is landfarmed at the Navy-operated Barbers Point Landfarm Facility.

Figure 3. NAVSTA Pearl Harbor, HI, SBR facility.
The microfilters, blowers, and system controls are housed in refurbished shipping containers. A 20,000 gal tank is used to receive and hold oily waste, which is treated in 1000 to 2000 gal batches in the 10,000 gal SBR.

Flow control valves are used to minimize the production of concentrate by the microfilter, currently 1.5 gal of concentrate for every 30 gal of permeate. Permeate produced by the microfilter is a dilute solution of inorganic nutrients that is either discharged to the sewer or used to dilute incoming oily sludge prior to charging the reactor (elevated salinity precludes any reclamation or recycling). The concentrate is discharged to a holding tank where it is held until it is landfarmed along with excess biomass in the SBR. This approach eliminates the need for landfilling and results in the essentially complete degradation of hydrocarbons and other organic components in the sludge leaving only process water and biomass as nontoxic byproducts.

The Pearl Harbor project has successfully treated more than 40,000 gal (~300,000 lb) of oily sludge from various sources including the BOWTS facility. This system made extensive use of surplus components (tanks, concrete pad and berm, microfiltration unit, and biofilters) that were available at the site, so it is not necessarily representative of the technology, waste stream, or climatic conditions at other activities. Furthermore, it has not been tested with other types of problematic oily sludge (e.g., emulsified oils, fuel tank bottom sludge) that more widespread implementation will require, including procurement of commercial components and disposal of

the residual solids that accumulate in the reactor. The effort at SCAAP was designed to dem/val an innovative application of bioreactor technology for treating a different type of oily sludge, specifically the spent forging lubricant sludge that is generated at SCAAP.

3.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The main advantages of the biological treatment are:

- Complete degradation of the hydrocarbons in oily sludge.
- High bacterial densities maintained by using a microfilter to capture and recycle bacteria.
- Permeate produced by the filter can potentially be recycled.
- Reactor system is simple to operate.
- Eliminates oily sludge handling and disposal.

The main limitations of the technology are:

- Excessive hydrocarbon loading can reduce effectiveness.
- Can be poisoned by extremes of pH, salinity, or high concentrations of heavy metals.
- Winter in Pennsylvania necessitates the use of an enclosed building to maintain a temperature of 70-80°F, which will be provided by capturing waste heat from the forges.

The major operational issues are ensuring that the Scranton Sewer Authority discharge limits are met and disposal of biomass that accumulates in the reactor when landfarming or composting is not an option. At Scranton, solids that include graphite will be captured in a filter press and disposed in a conventional landfill.

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4.0 PERFORMANCE OBJECTIVES

The quantitative and qualitative performance criteria, metrics, and results are summarized in Tables 1 and 2, respectively.

Table 1. Quantitative Performance Objectives.

Performance Requirement	Metric	Data Requirement	Success Criteria	Results
Primary Quantitative Performance Objectives				
Reactor performance hydrocarbon degradation of the forge sludge	Hydrocarbon concentration in the treated effluent	SW846 Methods: 8015M 8270B - GC/MS	<100 ppm	<50 ppm
Cost reduction – includes capital and O&M	Payback compared to current practice	Standard cost tracking and accounting practices	<2 years	~3 years
Discharge treated wastewater to the sewer	Wastewater discharge permit requirements	Standard analytical methods specified by the Sewer Authority	Meet permit limits	Permit limits met
Air emissions	Concentration of VOCs in SBR exhaust air	SW 846 Methods: 8010 5030 - Purge and Trap, GC/MS	Meet permit requirements	Air emission limits met
Waste disposal	Metals concentration in the solid waste	TTLC - Metals	Meet permit requirements	Solid waste permit limits met
Secondary Quantitative Performance Objectives				
Treatment time	Hydraulic residence time	Achieve targeted hydrocarbon concentration in reactor effluent	<8 days	5-9 days

Notes:
GC = gas chromatography
GC/MS = gas chromatography mass spectroscopy
TTLC = total threshold limit concentration

Table 2. Qualitative Performance Objectives.

Performance Requirement	Metric	Data Requirement	Success Criteria	Results
Ease of component procurement	Off-the-shelf items and on-time delivery	Project experience	Ready availability of off -the-shelf components	No delays in procuring components
SBR assembly	Within contractors estimate	Project experience	Does not require overly complicated installation requirements	SBR assembled and modified as required on site.
Start up and optimization	Within projected project timeline	Project experience	Within the projected schedule	Unanticipated changes delayed start up and optimization.
Ease of O&M	Actual time-Compare to current practice	Project experience	Requires only routine maintenance of pumps, valves, and sensors	With the exception of the microprocessor, the system is easily maintained.
Operator safety	Compare to current practice	Project experience	Operation does not create a safety hazard	No safety issues have been identified.
System reliability	System downtime - uptime	Project experience	System works month-to-month as designed	Various pump seals may not be appropriate for this application.

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5.0 SITE/PLATFORM DESCRIPTION

5.1 TEST PLATFORMS/FACILITIES

SCAAP (Figure 4) is a government-owned contractor-operated facility. It is located in Scranton, PA, and occupies 15.3 acres of the former Delaware, Lackawanna, and Western Railroad and has been used for heavy industrial fabrication and manufacturing since the mid-1800s. Buildings currently used by the Army were constructed between 1907 and 1909 and until 1947 were used for building and repairing steam locomotives and manufacturing T-rail for the railroad. The Army bought the property in 1951 and over the next 2 years installed the forges and mills that are used to produce large caliber projectiles. The original contractor was the U.S. Hoffman Machinery Company, and in 1963, Chamberlain Manufacturing Corporation became the contractor and operated the plant until 2006 when it was acquired by General Dynamics. The plant was modernized in 1967 and plans for updating the plant are in progress.

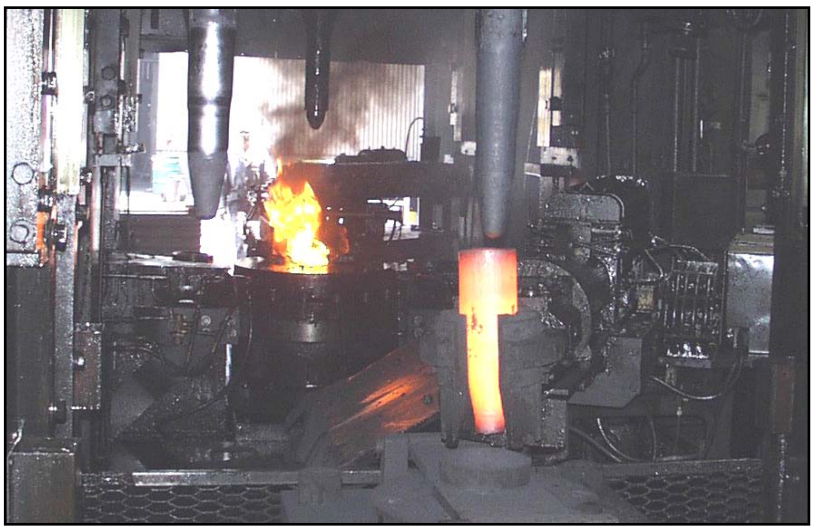

Figure 4. The SCAAP forging operation.
A robotic arm removes a red-hot freshly forged projectile (foreground) from the forge (background). The forge oil is easily ignited at the forging temperature (~2300°F).

5.2 PRESENT OPERATIONS

Scranton was chosen because the sludge is a very challenging thermally degraded petroleum waste that differs chemically and physically from more traditional oily sludge recovered from the BOWTS system, vehicle wash racks, and tank bottoms. To validate on-site treatment technology and demonstrate a wider applicability, it is essential to show that it works with a wide variety of oily wastes and sludge. In addition, the temperature in Scranton drops below freezing in the winter, which necessitates that the facility is installed in a heated building, which constrains design flexibility. Since the plant is an essential DoD facility that cannot be moved or replaced, the SCAAP waste presents a challenging waste stream in a unique industrial setting and environment.

5.3 SITE-RELATED PERMITS AND REGULATIONS

Liquid Effluent. To treat oily waste from its forging operations, SCAAP currently operates an Oily Wastewater Pretreatment Plant (OWPP). Discharges to the sewer from OWPP must meet the permit standards established for the entire plant (Table 3). Since the biological treatment system is tied into OWPP, only a request a to modify the current permit is necessary. However, wastewater discharged from the biological treatment system must comply with the requirements of the existing permit.

Table 3. Sewer discharge limits for SCAAP wastewater and analytical results for wastewater produced during biodegradation of SCAAP oily sludge.

Parameter	Sample Results (mg/L)	SCAAP Limit (mg/L)
Cadmium	BQL	0.23
Chromium – hexavalent	BQL	1.4
Chromium – total	0.12	2.77
Copper	2.6	0.23
Lead	0.066	0.69
Mercury	BQL	0.005
Nickel	1.6	2.8
Silver	0.014	0.16
Zinc	0.72	2.61
Cyanide – total	BQL	1.2
Toluene	BQL	0.8
Xylenes – total	0.6	3.0
BOD	130	7,000
Ammonia nitrogen	130	375
Total suspended solids	7530	Monitor for surcharge
Floatable oils and grease (FOG)	NT	No FOG
FOG - petroleum origin	88	100
FOG – total	110	1500
Color (C.U.)	100	200
Methylene blue active substance (MBAS)	3.9	5.0
pH range (S.U.)	6.8	6.0 to 9.0
Total toxic organics (TTO)	BQL	2.13

Notes:
BQL: below quantitation limit
NT: not tested

The results (Table 3) show that the wastewater discharged from the SBR meets the requirements for wastewater discharged from the OWPP to the sanitary sewer. The exception is copper, which compared to historical data for wastewater from the OWPP is anomalously high (historical monthly average is 0.2 mg/L). If copper or other metals prove to be a problem, they can be removed at the end of the process by passing the wastewater through an adsorbent column.

Wastewater samples were also analyzed for VOCs and semivolatile organic compounds (SVOCs) with all compounds reported as BQL.

Solid Waste. Solid waste produced by the treatment process is recovered using a filter press. This waste consists of biomass and graphite that is a component of the forge lubricant. The toxicity characteristic leaching procedure (TCLP) data (Table 4) show that the concentrations of all metals (with the exception of barium) were below the practical quantitation limit (PQL) (range 0.005 – 0.1 mg/L), and the concentration of all metals is less than the soluble threshold limit concentration (STLC) limits for landfill disposal.

Table 4. Analytical results for reactor solids and STLC limits for land-filling solid waste.

Metal	STLC Limit (mg/L)	TCLP Result (mg/L)	PQL (mg/L)
Arsenic	5	BQL	0.01
Barium	100	0.036	0.02
Cadmium	100	BQL	0.01
Chromium	560	BQL	0.01
Lead	5	BQL	0.1
Mercury	0.2	BQL	0.005
Selenium	1	BQL	0.01
Silver	5	BQL	0.01

Notes:
BQL: below practical quantitation limit

Air Emissions. Since oily sludge may contain VOCs that would be emitted during vigorous aeration of the reactor, air samples were taken within 1 hour of charging the SBR with fresh oily sludge and analyzed for priority air pollutants (USEPA Method TO14), which analyzes for 35 compounds. The concentrations of all VOCs with the exception of benzene and toluene were less than the PQL (0.06 – 0.28 ppm), Table 5. To ensure that no VOCs are emitted, exhaust air is passed through activated carbon. It should be noted that the original proposal called for biofilters; however, for the low concentrations of VOCs, activated carbon is more practical and cost effective.

Table 5. Compounds detected in air emissions from the SBR.

Compounds Detected	Concentration (ppm)	OSHA Limits (ppm)
Benzene	0.8	10
Toluene	1.1	200

Notes:
OSHA = Occupational Safety and Health Administration

The results presented here and data from previous pilot scale and prototype (Hawaii) demonstrations of oily sludge biodegradation show that the wastewater, solids, and air emissions consistently meet the compliance and regulatory limits, including those set by the city of Scranton and the state of Pennsylvania.

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6.0 TEST DESIGN

6.1 TEST AND FACILITY DESIGN

When the project was proposed, the SCAAP OWS (Figure 5) would continue to be used and the SBR would be used to treat the sludge recovered from the OWS. However, this approach would have required considerable additional plumbing and the recovered sludge would have to be diluted to a concentration appropriate for biological treatment. As more detailed operational data became available, the concentration of hydrocarbons in the wastewater was determined to be well within the range for biological treatment. Thus, the treatment system was designed so that the wastewater recovered from the sumps could be fed directly into the SBR. This approach eliminated the need for the OWS and fresh water to dilute the concentrated sludge.

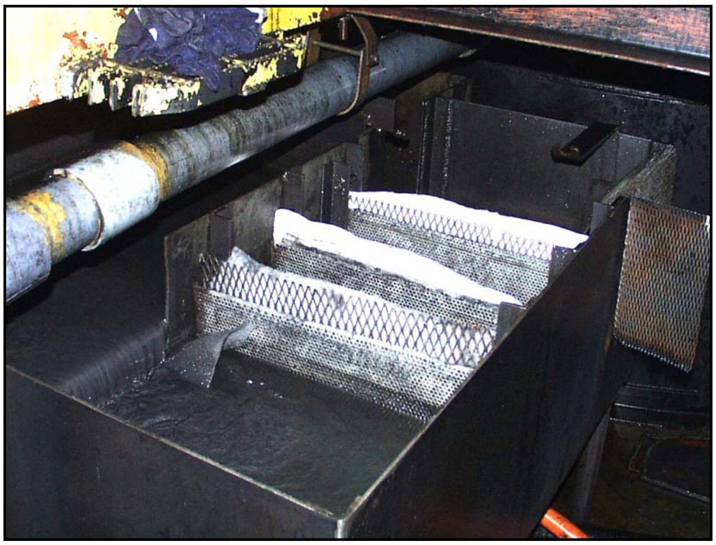

Figure 5. Scranton OWS uses adsorbent pads to remove residual oil prior to discharging the wastewater to the sewer.

Initially, SCAAP produced ~300,000 gal of oily wastewater per month (500,000 gal peak) and recovered ~700,000 lb of sludge per year from the OWS and ~200,000 lb from the trenches under the forges. If sludge from the trenches were suspended in the wastewater, the total average monthly load of sludge in the wastewater would be 75,000 lb (i.e., (700,000 + 200,000)/12 months) and the average combined hydrocarbon concentration in the wastewater would be ~30,000 ppm. However, the average hydrocarbon concentration in the sludge is 20% by weight, which suggests that if all of the waste were combined the total hydrocarbon concentration would be one-fifth of 30,000 ppm or ~ 6000 ppm.

Since the system in Hawaii takes 5 days to degrade the equivalent hydrocarbon concentration to 100 ppm, it would be expected that 5 to 6 days of treatment would reduce the concentration to or below the SCAAP discharge limit. To provide 6 days of treatment at a maximum flow of 500,000 gal of wastewater per month would require 100,000 gal of reactor capacity. Because of floor loading and space limits, a single large reactor was not practical or necessarily desirable so two 50,000 gal SBRs were installed.

In addition to the SBR, the major subsystems are nutrient addition; pH control; aeration; a membrane filter, which is used to remove residual solids from the settled wastewater discharged during the decant phase; a filter press that is used to capture wasted biomass and solids (primarily graphite) that accumulate in the SBR along with concentrate from the filter, which are dried and landfilled; and carbon canisters to capture VOCs in air vented from the SBR. Clean water is stored and can be used for makeup water in the SBR. However, all of the filtrate is currently used for cooling water and it has not been necessary to discharge to the sewer. These components, inputs, and outputs are shown in the process diagram (Figure 6).

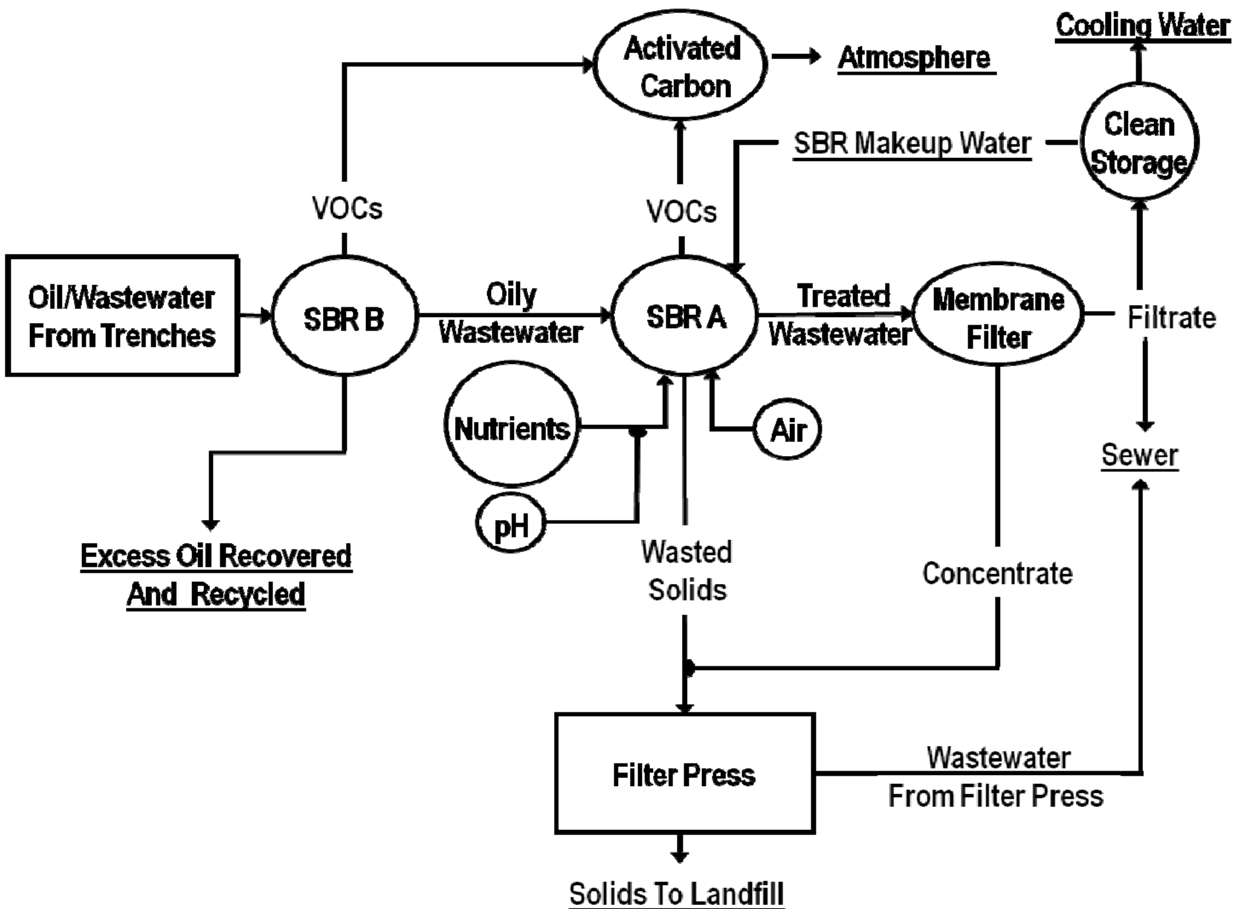

Figure 6. Process diagram for the SCAAP oily wastewater treatment system.

As will be discussed in Section 6.1, it was necessary to modify the treatment system to accommodate unexpected properties of the oily waste and changes in how SCAAP managed their wastewater. The process diagram (Figure 6) reflects these changes. Briefly, SBR B is used as a gravity separator and a skimmer was added to recover oil, which is recycled. This was possible because changes in wastewater management reduced the volume of wastewater but not that of the oil, much of which is recovered and recycled. As a result, the residual oil concentration in the wastewater is a few hundred ppm, which is degraded in SBR A.

As with previous work, pilot studies were used to determine if it was feasible to treat the SCAAP sludge. These studies used a 20 gal air lift reactor (Figure 7) equipped with a pH controller and oxygen electrode. Sludge recovered from the trenches and OWS was mixed with nutrients, and at regular intervals samples were analyzed by total petroleum hydrocarbons (TPH) and bacteria (heterotrophs and hydrocarbon degraders). Representative data are shown in Figure 7 and show that the hydrocarbons in the sludge were degraded within 4-5 days to less than 100 ppm, which coincided with an increase in the population of hydrocarbon-degrading bacteria. Chromatograms (not shown) of the oil sludge extracted confirm that extensive degradation of the hydrocarbons in the sludge occurred. These tests demonstrated that biological treatment of the SCAAP oily sludge was technically feasible and a full-scale system was designed and installed.

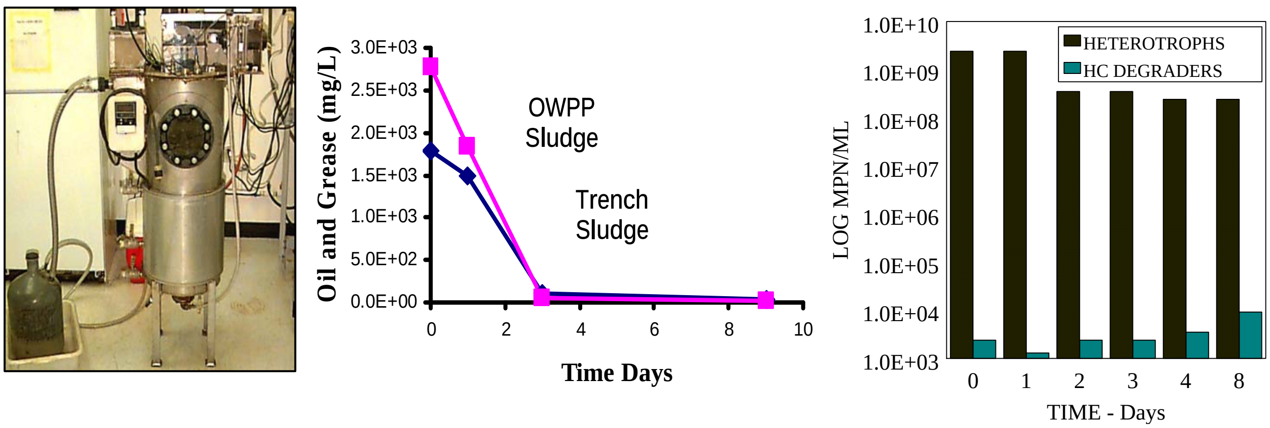

Figure 7. Biodegradability testing of SCAAP oily sludge in a pilot reactor (left) demonstrated that sludge from two sources (OWPP and trenches) in the plant was rapidly degraded (middle), which coincided with an increase in the number of hydrocarbon- degrading bacteria (right).

A plan view and vertical section of the treatment system in shown in Figure 8. Since the treatment system is located on the roof of the lower level of the plant, the floor, which dates to the early 1900s, had to be tested to ensure that it was capable of supporting the weight of the two SBRs when they were filled with water. Once it was determined that the floor would support the SBRs, a piping and instrumentation drawing (P&ID) was prepared (Figure 9), and the building that houses the treatment system was built and the treatment system installed.

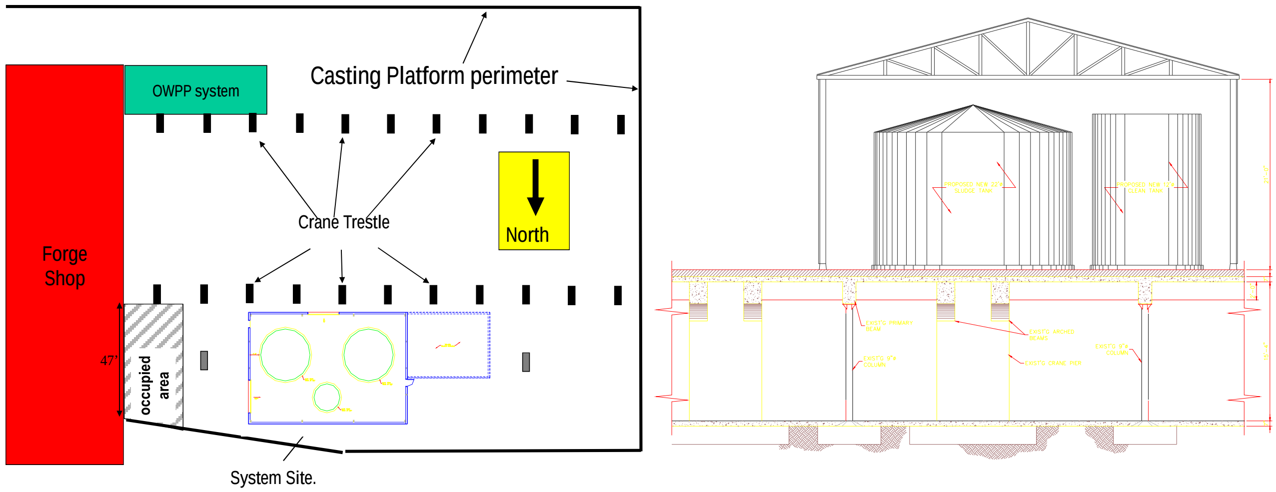

Figure 8. Plan view (left) and a vertical section (right) of the treatment plant.

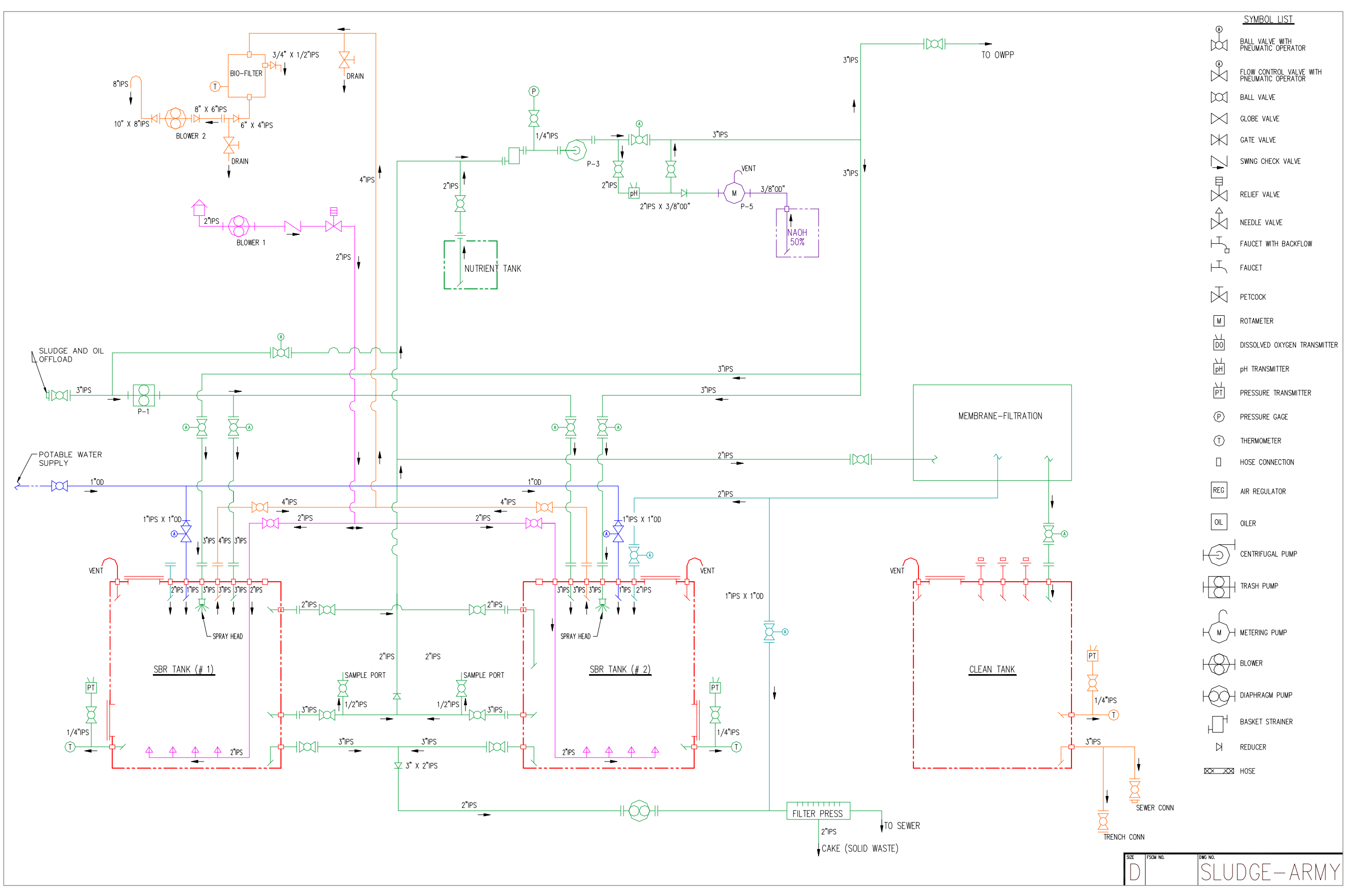

Figure 9. A P&ID of the treatment system.

The process diagram (Figure 6) shows final configuration of the system including the products: (1) air vented from the SBRs is scrubbed of VOCs by passing it through activated carbon before it is vented to the atmosphere; (2) excess oil is recovered and recycled; (3) a filter press is used to dewater solids (wasted biomass and graphite from the SBR and concentrate from the filter) and the dewatered solids are landfilled (nonhazardous) and the water discharged to the sewer; and (4) treated wastewater decanted from the SBR is filtered to remove residual solids, and the filtrate is stored on site and is currently used as cooling water in the plant. It can also be used as makeup water in the SBR or discharged to the sewer.

The major operational phases of the project are summarized in Table 6. Structural testing of the floor delayed start-up 6-7 months and the installation was not completed until late 2005. After testing the functioning and integrity of the system, testing with oily wastewater (referred to Phase I) was initiated. Even though the initial results showed that the oily sludge was rapidly degraded, as testing progressed, it was recognized that the system as installed did not provide adequate mixing. Modifications to correct these problems were designed and installed in the second and third quarter of 2007 and testing resumed.

Table 6. Summary of the major project phases.

Project Phase	2005		2006				2007				2008				2009	
	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
Installation completed	■	■														
Phase I testing			■	■	■	■	■									
System modifications								■	■							
Phase I testing continued										■	■					
System modifications												■	■			
Phase II testing														■	■	■

However, the concentration of oil entering the reactor greatly exceeded what was expected and was beyond the design capacity of the system. Discussions with SCAAP revealed that new wastewater management policies had reduced the wastewater flow by one third from 300,000 gal per month to slightly more than 100,000 gal per month. In addition, the trenches were being used as gravity OWSs, and to meet the discharge limits, only the lower water layer was being treated at the OWPP. Thus, when the SBR was charged following the modifications, the concentration of oily sludge exceeded 40,000 ppm, which was 6-7 times the expected concentration (6000 ppm). This problem was addressed by using SBR B as a gravity OWS and installing a skimmer in the SBR that removed the floating oil, which is sold to a recycler for \$0.85 per gallon. Following these modifications, testing (referred to as Phase II) was resumed and completed during the first two quarters of 2009.

6.2 SAMPLING AND TESTING

At regular intervals, the pH, temperature, and dissolved oxygen (DO) concentration reported by sensors in each tank were recorded along with the cumulative operating time of the pH pumps. Wastewater in the SBR was sampled during the react cycle and analyzed on site using Hach kits for ammonia nitrogen, reactive phosphorous, suspended solids, and turbidity.

Samples from the SBR were also sent to a commercial lab and analyzed for hydrocarbons, metals, and solids (total and volatile), 5-day biochemical oxygen demand (BOD_5), and chemical oxygen demand (COD). To ensure that regulatory requirements were met, samples of exhaust air and solids were also analyzed. The analyses, sampling points, relative frequency, and where appropriate the quantitation limit are summarized in Table 7.

Table 7. Summary of analytical methods, sampling frequency, and method limits.

Parameter and Method	Medium and Sampling Frequency	Quantitation Limit
Commercial Laboratory Analyses		
Total recoverable petroleum hydrocarbons (TRPH) USEPA Method 1664 TPH 8015M	Daily/weekly samples from the SBR and effluent	20 - 100 μg/L
VOCs SW 846 Methods: 8010, 8015A, 5030	Air entering and exiting the carbon filters	5 – 20μg/L
Mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS), an indirect measure of biomass Standard Method 2540E	Daily/weekly Samples from the SBR	1 mg/L
Total suspended solids (TSS) Standard Method 2540 D	Daily/weekly samples from the SBR	1 mg/L
Metals Standard Method 3120 B ICP	Monitor metals in the SBR and solids	2- 100 μg /kg
BOD_5 Standard Method 5210 A	Weekly samples from the SBR	1 mg/L
On-Site Analyses		
Inorganic species Hach Kits	Daily/weekly samples from the SBR to adjust nitrogen and phosphorous as required	0.03 – 0.05 mg/L
Process Monitoring		
pH calibrated pH electrode	Monitoring pH in the SBR	Process Specific
Oxygen concentration oxygen electrode	Monitoring oxygen in the SBR	0.2 mg/L
Liquid flow calibrated flow meters	Monitoring wastewater flow into the SBR	Process specific
Air flow calibrated flow meters	Monitoring air flow in the SBR and carbon canisters	Process specific

Samples were also taken on the discharge side of the tube filter and sent to a commercial lab where they were analyzed for the analytes specified by the Scranton Sewer Authority (Table 3).

6.3 TESTING RESULTS

Phase I. After the treatment system was installed and the integrity verified, one of the SBRs was charged with oily wastewater, amended with nutrients, and sampled at regular intervals. The results (Figure 10 and Table 8) show that the oily waste was rapidly degraded and the concentrations of metals of concern in the solids were below the PQL and or regulatory levels.

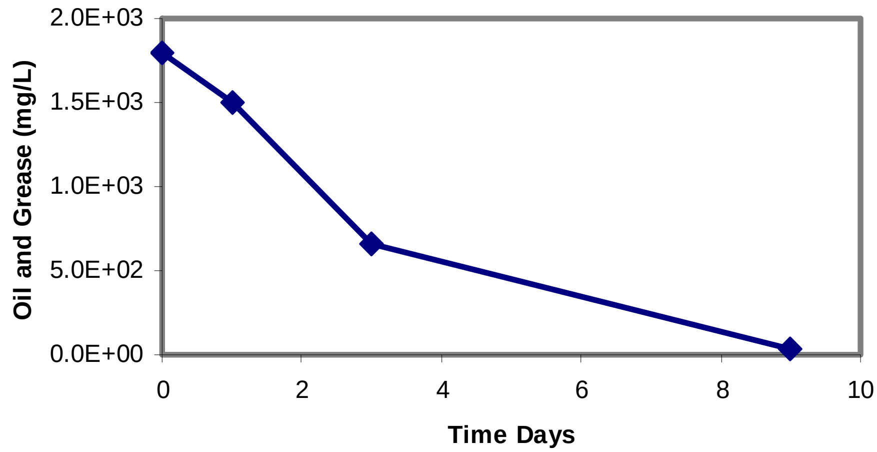

Figure 10. Degradation of oil and grease in the SCAAP SBR.

Table 8. Concentrations (TCLP) of select metals in the SCAAP SBR solids.

Metal	Concentration (mg/L)
Arsenic	BQL[1]
Barium	0.034
Cadmium	BQL
Chromium	0.034
Lead	BQL
Mercury	BQL
Selenium	BQL
Silver	BQL

However, the performance of the treatment system degraded over the next few months, and during a site visit it appeared that the major problem was inadequate mixing which, allowed the oil to pool on the surface where it congealed and sank to the bottom of the SBR. To correct this problem, a more efficient aerator and a surface weir that captured and recirculated pooled oil were designed and installed in July and August 2007.

Oil and polysaccharides, which previously floated on the surface of the SBR, were drawn into the weir (Figure 11) and mechanically emulsified by the recirculation pump. (It should be noted that the residual polysaccharide, which the bacteria synthesized when the nitrogen concentration was too low, should not be a problem in the future.) Since the treatment system relies on mechanical emulsification of the spent forging oil, the weir appeared to function as designed, which was confirmed during subsequent testing.

Figure 11. Oil and polysaccharide emulsification following installation of the weir. Polysaccharide and oil on top of the tank prior to starting the recirculation pump (left), flowing in the weir (center), and emulsified polysaccharide and oil (right).

Once SBR A was filled, the hydrocarbon concentration rapidly decreased over the course of 4 days (28 September–1 October) from ~30,000 ppm to ~5000 ppm (measured with the Horiba instrument) (Figure 12). As was expected, the decrease in hydrocarbon concentration was accompanied by a rapid increase in the consumption of sodium hydroxide, which neutralizes the intermediate carboxylic acids produced during hydrocarbon breakdown. That the degradation of the oil was caused by bacterial growth is shown by the increase in biomass, which parallels the decrease in the hydrocarbon concentration, Figure 13.

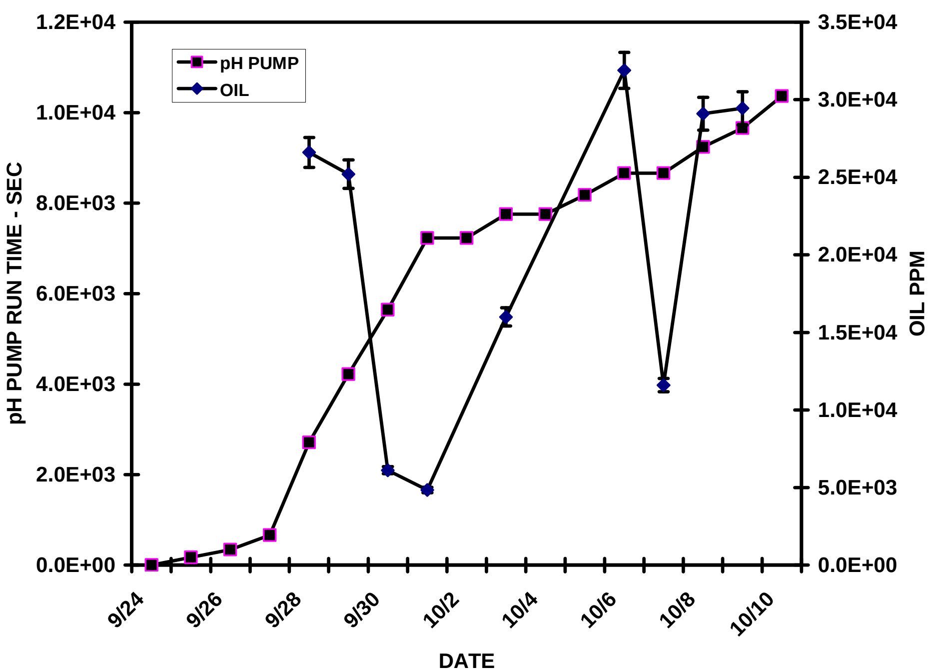

Figure 12. Hydrocarbon concentration and sodium hydroxide consumption in SBR A.

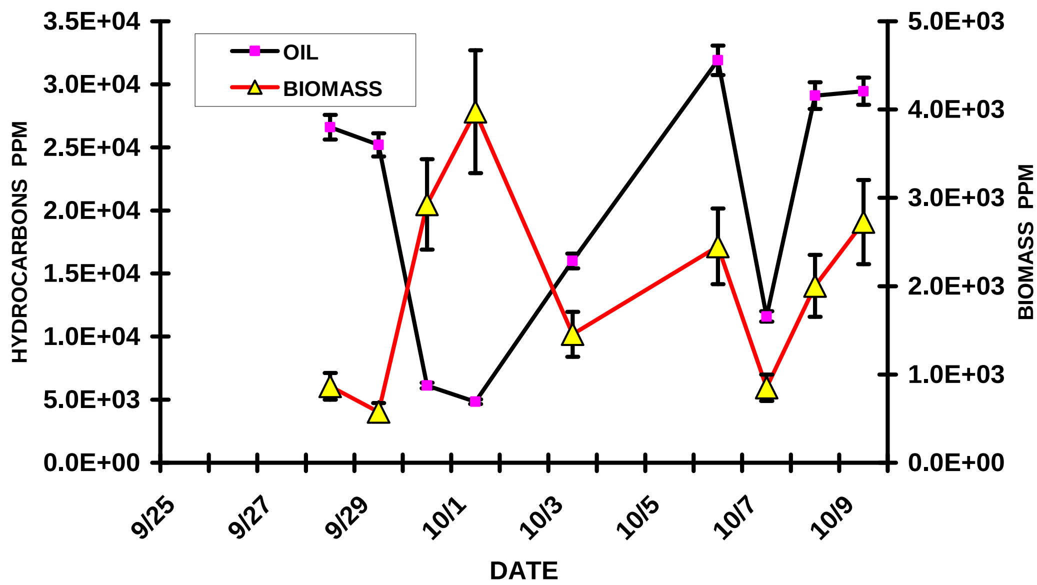

Figure 13. Concentration of biomass and hydrocarbons in SBR A.

After 4 days the data (Figure 12) suggest that the hydrocarbon concentration increased. However, this is probably due to an artifact of the 418.1 method using the Horiba instrument, which does not distinguish hydrocarbons present in the wastewater from hydrocarbon-like molecules produced by and found in the biomass. These compounds (e.g., fatty acids, which are fond of all cellular organisms) are extracted along with the hydrocarbons and inflate the hydrocarbon concentration. This interpretation is supported by reports in the literature (e.g., http://www.google.com/#sclient=psy&hl=en&q=method+418.1+interference&aq=f&aqi=&aql=&oq=&pbx=1&fp=38ed6da7faad07f1) and data in Table 7 which shows that hydrocarbon concentrations measured with the Horiba instrument are more than an order of magnitude higher than the values reported when USEPA Method 8015m was used.

Overall, the data are consistent with what was observed in the pilot studies and our experience with this treatment system. Even though the decrease in oil concentration was significant, it is not sufficient to meet the discharge requirements. However, the concentration of oil (~30,000 ppm) was five times higher than what the system was designed to treat. While additional degradation may have occurred if the system was supplemented with micronutrients and operated in series, it is doubtful that the target of <100 ppm would have been achieved.

As was previously discussed, the amount of oil pumped into the reactor had been accumulating in the trenches for 1-2 months prior to start up of the system and may not be representative of the average daily production of waste oil. In fact, the hydrocarbon concentrations in recent samples from two of the sumps were 4700 ppm and 2400 ppm. From the pilot study, these are typical of the concentrations that were expected and which the system should be able to treat to meet the discharge requirements.

Testing of the modified treatment system demonstrated the capabilities of the system. However, changes in the way SCAPP manages its wastewater resulted in higher than expected hydrocarbon

concentrations (>40,000 ppm), and because of the heavy nature of these hydrocarbons, the system cannot degrade it in a reasonable time and meet the discharge requirements.

To remove and recycle the excess oil, SCAAP installed an oil skimmer in SBR B (Figure 14). It should be noted that the more concentrated oil stream makes it cost effective to recover and recycle it rather than simply dispose of it. A further advantage of this approach is that the hydrocarbon concentration in the wastewater going to the SBR A is more consistent (2000 – 4000 ppm), which makes the system more stable, easier to operate, and less susceptible to system upsets caused by too much or too little oil.

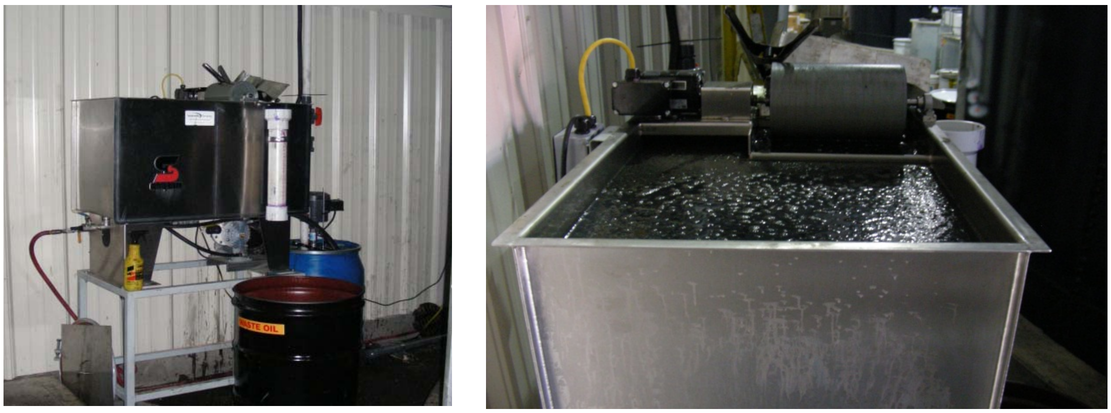

Figure 14. Oil skimmer installed at Scranton Army Ammunition Plant.
Floating oil in SBR B is skimmed and pumped to the drum skimmer where the oil is recovered and water is returned to the SBR. The processing rate is 25 gal per hour.

Phase II Testing. In early November 2008, SBR A was filled to its working capacity (40,000 gal) and nutrients added as required. Samples were taken from the reactor before and after it settled and the filtrate that passed through the tube filter. Samples were analyzed on-site (Table 9) and samples were also sent to a commercial lab and analyzed for hydrocarbons, total organic carbon (TOC), total suspended solids, and volatile suspended solids (VSS). Samples were also sent to an off-site lab for analysis of TPH USEPA method 8015, TOC, MLSS, MLVSS, and the results are included in Table 9. In contrast to the hydrocarbon concentration measured on site with the Horiba instrument, the TPH concentration measured using gas GC was reduced from 157±14 ppm in the incoming wastewater to 16±12 ppm in the treated wastewater that passed through the tube filter filtrate after the SBR was settled. As the hydrocarbons were degraded, there was a transient increase in TOC and MLVSS, which are indirect measures of bacterial growth (Figure 15).

Table 9. Phase II analytical results.

Date	Nitrogen	Phosphorous	TPH		Turbidity	Solids			DO	pH	T °F	TOC	COD
			Horiba	GC		TSS	MLVSS	MLSS					
React													
10/31/08				157±14			930±71	1305±488				335±21	5760±905
11/01/08	406	175	560		510	665			8.24	9.62	69.3		
11/08/08				120.2			1770	1960	7.3	8.08	79	500	7910
11/10/08				42			1770	2400	8.2	8.33	80.78	270	7790
11/11/08									7.1	8.20	81.68		
11/12/08				4			1800	2010	7	8.18	82.58	150	6630
11/13/08									7	8.16	84.02		
11/14/08				12.6			1750					140	6400
11/18/08	152	255	427	8.5±1.3	1515	2200	1075±191	1460±170				155±21	4190
Settle													
11/18/08					70	30							
11/19/08					78	34							
Filtrate													
11/18/08					69	25							
11/9/08			556	16±12	75	31	105±7	145±7				155±7	1120

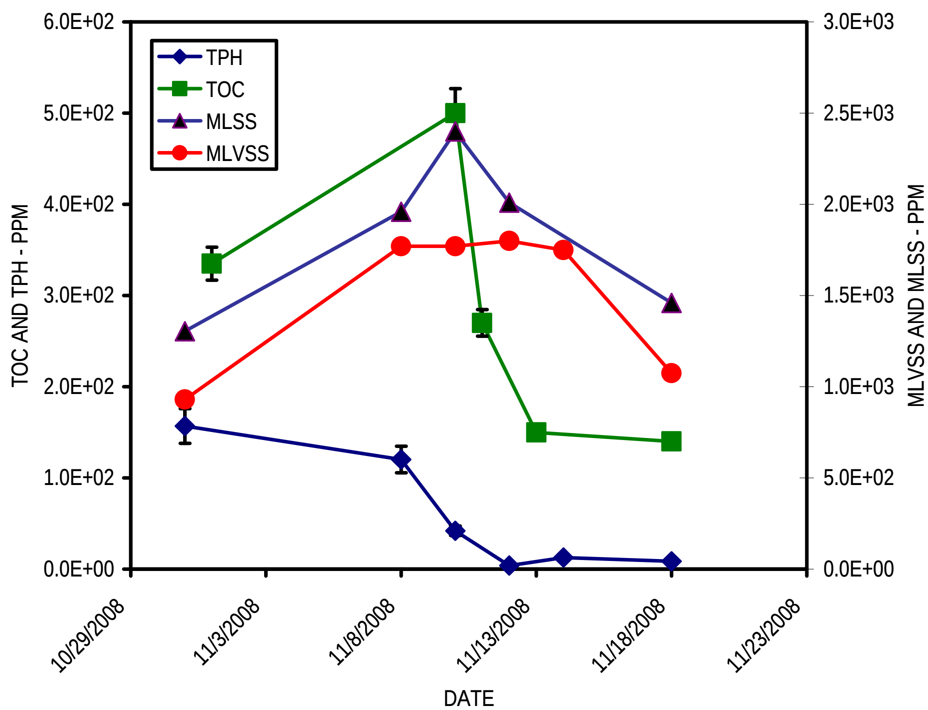

Figure 15. TPH, TOC, MLSS, and MLVSS during the react cycle.

Phase II Testing Continued. A second round of testing was conducted in February 2009, and the results of the on-site and commercial lab analyses are summarized in Tables 10 and 11, respectively. As would be expected in a well-behaved system, the nitrogen and phosphorous were consumed and these parallel increases in turbidity and TSS (indirect measures of biomass) and the degradation of the oily sludge (Tables 10, 11, Figure 16). Petroleum hydrocarbons measured as TRPH by the method specified by the Scranton Sewer Authority (Method 418.1) showed that the forging fluid hydrocarbons are degraded to below the discharged limit (Table 11).

Table 10. Phase II on-site analyses (average and standard deviation).

Date	Turbidity[1]	TSS[2]	Phosphate	Ammonia	Sulfate	Nitrate	Nitrite	Fatty Acids
2/25/09	3625	5000	169±34	66.1±6.7	35	0	0	1681±221
2/26/09	4000	5300	167±15	66.1±6.7	35	1.88±0.88	0	2019±405
2/27/09	Nutrient Addition							
3/3/09	4000	5300	177±40	185±7	25	10.8	0	1214±138
3/5/09	2050	2675	178±22	177.5±10.6	35	23.3	0	1309±244
3/10/09	3100	3950	153±28	36.1±16.7	30	1.7	0	1548±410
3/12/09	3050	3675	148±26	22.2±13.4	30	0.8	0.2	1646±171

Notes:
[1]Turbidity units are Formazin Nephelometric Units (FNU); all others are ppm.
[2]TSS- total suspended solids

Table 11. Phase II commercial lab analyses.
(Units are ppm.)

Date	TRPH[1]	BOD_5[2]	MLSS[3]	MLVSS[4]	COD[5]
2/25/09		298	5100	4780	5805
2/26/09		143	7320	6960	14,000
2/27/09		106	4600	4333	
3/3/09	13	85.8	3900	3600	4770
3/5/09	<5	70.5	4100	3833	8033
3/10/09	20	389	1733	1567	4214
3/12/09	47.9	382	2300	2133	4674

Notes:
[1]TRPH - total recoverable petroleum hydrocarbons
[2]MLVSS - mixed liquor volatile suspended solids
[3]MLSS - mixed liquor suspended solids
[4]BOD_5 - biological oxygen demand
[5]COD - chemical oxygen demand

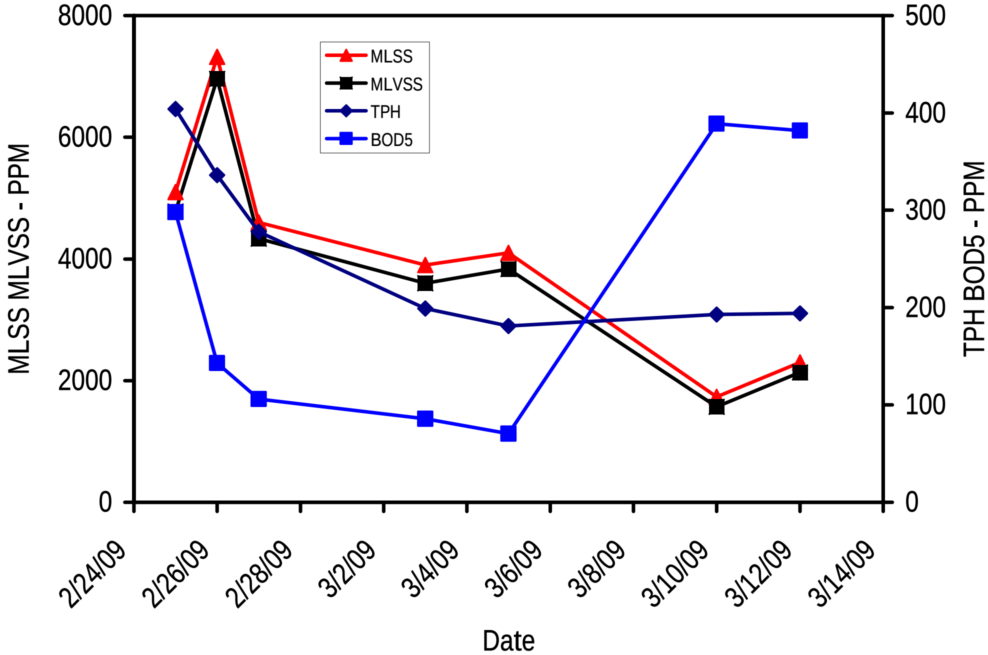

Figure 16. MLSS, MLVSS, TPH, and BOD_5 during the react cycle.

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7.0 PERFORMANCE ASSESSMENT

7.1 PRIMARY QUANTITATIVE PERFORMANCE OBJECTIVES

Hydrocarbon Degradation. Although the start-up of the treatment system experienced some setbacks related to inadequate mixing and changes in the management of the wastewater by SCAAP, the Phase II testing (two rounds) demonstrated that the hydrocarbons in the spent forge lubricant were easily degraded to below the regulatory requirements within the design hydraulic retention time (Tables 9 and 11 and Figures 15 and 16). In addition, the wastewater discharge from the treatment system meets the limits set by the Scranton Sewer Authority, the minimal air emissions are captured with activated carbon filters, and the solid waste is not hazardous (Tables 1, 2, and 3). Errors associated with sampling and analyses were estimated by analyzing three separate samples in triplicate (i.e., nine separate analyses) from which the average and the standard deviation were calculated. The percentage of the standard deviation for each analysis was expressed as a percentage of the average value and used to estimate the error for the individual measurements.

Reactor Optimization. Data (Figure 17) were also collected that show that a consortium of highly desirable, rapidly settling (<2 hours) bacteria as opposed to the non-settling or bulking and filament rich variety established in the SBR. To further reduce the loading of suspended solids in the filtrate, the settling phase can be progressively shortened which selects for bacteria that settle even more rapidly (i.e., biomass that remains suspended is drawn off during decant).

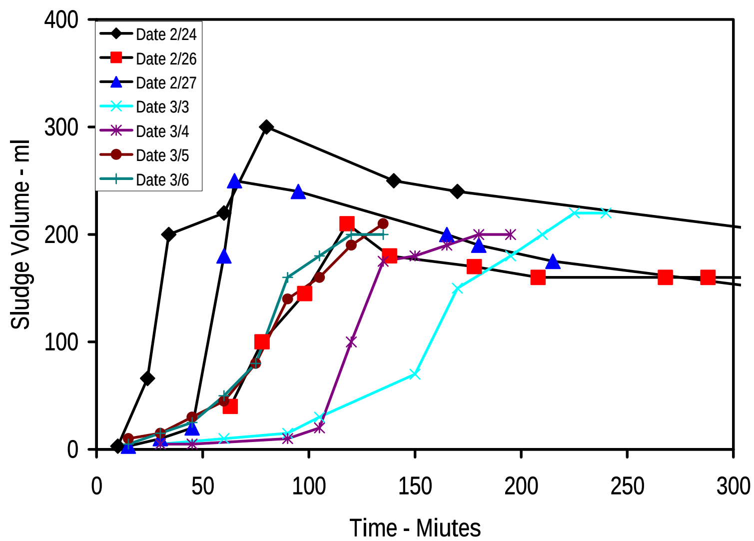

Figure 17. Sludge settling and equilibrium sludge volume.

Since the bag filter removed little if any of the remaining solids (i.e., turbidity and TSS in the settled SBR were 78 and 34, respectively, and in the filtrate the corresponding values were 75 and 31, respectively, [Table 9]), it may be possible to replace the 1-5 µm tube filter with a microfilter that would remove more of the particulates. However, the exact filtration requirements will be determined by the discharge permit requirements.

The BOD_5 and MLVSS values were used to calculate the food to microorganism (F/M) ratio (Figure 18), a parameter commonly used to optimize reactor performance. The relatively constant F/M ratio during the react cycle (Figure 18) was accompanied by a decrease in hydrocarbons and other nutrients which were converted to biomass measured indirectly by TSS and turbidity which increase in proportion to the amount of available food (i.e., F/M remains relatively constant until the end of the react cycle). The increase in the BOD_5 towards the end of the react cycle may have been, as previously discussed, due to the production of degradation intermediates would seem to be confirmed by the transient increase and subsequent decrease in the F/M ratio back towards its equilibrium value. Death and lysis of the microbial biomass could also increase the BOD_5 (i.e., release of cell components) and decrease the MLVSS is also consistent with the data. As a more optimally adapted bacterial population accumulates in the SBR, the F/M ratio would be expected to stabilize around a value that is a function of the hydrocarbon loading, active biomass, and residence time in the SBR (assuming that the average daily wastewater production continues to be 4,000 gallons and the hydrocarbon concentration remains at 100-500 ppm).

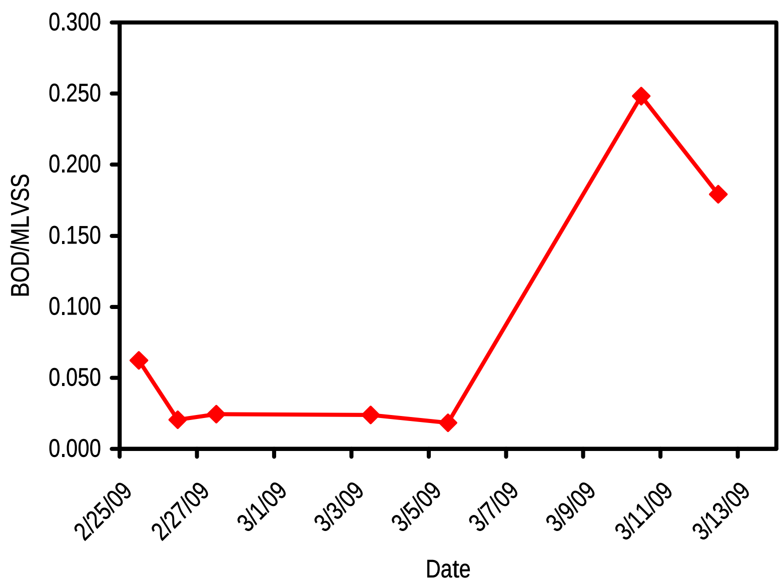

Figure 18. Value of the food to microorganism ratio (F/M).

Cost Savings. The cost analysis (Section 8.0) shows that on-site treatment is cost-effective with a projected payback of approximately 3 years. It should be noted that this does not include the value of the recycled oil (currently $0.85 per gal).

7.2 SECONDARY QUALITATIVE PERFORMANCE OBJECTIVES

The primary difficulties encountered with implementing the project were that the mixing and agitation were not adequate and had to be redesigned and installed. However, these changes were easily accomplished on site. An additional and unanticipated change was how SCAAP managed the wastewater, which reduced the volume at least threefold and a concurrent tenfold increase in the amount of oil. This change resulted in the installation of an oil recovery system with the oil being sold to a recycler and changes in how the SBRs were configured and operated.

However, the effluent from the SBR easily met the Scranton Sewer Authority permit requirements.

Experience with the modified treatment system has revealed recurrent problems with some of the pump seals suggesting that the seals may not be appropriate for this waste stream. In addition, the Allen Bradley microprocessor used to control the system seems unnecessarily complex for this application and alternatives should be investigated.

Overall, the treatment system was easily assembled and modified using commercial off-the-shelf (COTS) components and met the quantitative and qualitative performance goals and has generated hands-on experience and design data for future installations.

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8.0 COST ASSESSMENT

8.1 COST MODEL

Table 12 summarizes the capital costs (2005 dollars) for the SCAAP treatment system, including the modifications. The O&M costs are summarized in Table 13. These costs are based on a system capable of treating 900,000 lb per year of oily sludge or 100,000 to 500,000 gal per month of oily wastewater with a nominal hydrocarbon concentration of 4000 – 8000 ppm.

Table 12. Capital costs for biological treatment of oily sludge (900,000 lb per year).

Item	Units	Unit Cost (2005$)	Number of Units	Total Cost
Tank SBR (40K gal) w/ aerators	ea	$55,000	2	$110,000
Receiving tank (10K gal)	ea	$8300	1	$8300
Tube filter	ea	$23,000	1	$23,000
Filter press	ea	$42,000	1	$42,000
Blowers	ea	$1400	2	$2800
Chemical feed system	ea	$900	2	$1800
Biofiltration (carbon filter drum)	ea	$1200	4	$4800
Level sensors & meters	ea	$1400	2	$2800
Control panel	ea	$3000	1	$3000
Piping material	ea	$6000	1	$6000
Valves	ea	$3000	1	$3000
Electrical	ea	$2500	1	$2500
Secondary containment	ea	$5000	1	$5000
Contingencies/misc.	ea	$6000	1	$6000
System modification	ea	$42,000	1	$42,000
Shipping cost	ea	$2000	1	$2000
Total equipment cost				$265,000
Installation Cost (30% of capital costs)				$79,500
Total installed cost				**$344,500**

Table 13. Yearly O&M costs for the SCAAP SBR.

Item	Units	Unit Cost	Number of Units	Cost
Electricity	KWhr	$0.120	20,000	$2400
Water & sewer	3600 gal	$13.00	140	$1820
Biomass disposal	gal	$0.55	6000	$3300
Nutrients	ea	$3000	2	$6000
Operating labor	hr	$50	400	$20,000
Plant overhead (105% of labor)	hr	$50	420	$21,000
Maintenance (3% of capital investment)	ea	NA	NA	$10,335
Total annual cost				**$64,855**

While some costs will be fixed simply by the size of the treatment system (e.g., SBR capacity, pumps, piping, etc.), the specific waste stream and or location may incur additional costs. Examples of problems and suggested solutions are given in Table 14. All of the solutions will incur additional costs that will have to be factored into the cost benefit analysis for that particular site and waste.

Table 14. Problems that may be encountered with individual waste streams and sites.

Problem	Requirement	Solution
Elevated VOCs	Air filtration	Install biofilter
Heterogeneous waste stream	A "homogeneous" waste	Preconditioning or mixing tank
Concentrated waste stream	Dilute the incoming waste	Use reclaimed water
Waste stream too dilute	Increase the concentration	Concentrate the waste using ceramic microfilters
Elevated concentrations of metals in the waste stream	Reduce the metal concentration	Use adsorbent, e.g., iron-activated alumina to remove metals
Temperature extremes at the site	Minimize temperature extremes	Additional ventilation at high temperatures and waste heat capture and insulation at low temperatures

8.2 COST ANALYSIS AND COMPARISON

Using the costs in Tables 12 and 13, single line depreciation was used to calculate the cost for treating the oily sludge at SCAAP in the modified SBR (Table 15). The cost to dispose of the oily sludge is in excess of $100,000 per year and does not include the O&M costs for the OWPP. This is a recurring cost and long-term liability. In contrast, biological treatment at $0.11 per pound (comparable to the cost in Hawaii) includes all O&M costs and depreciation (but does not include the return for selling the waste oil) and the payback is approximately 3 years.

Table 15. Treatment cost based on single line depreciation.

Capital Cost	Cost O&M	Salvage Value	Yearly SLD
$344,500	$64,855	$0	$99,305
		Treatment cost per pound	**$0.110**

The cost analysis along with the performance data demonstrates that on-site biological treatment of oily waste is technically feasible and cost effective.

9.0 IMPLEMENTATION ISSUES

This project demonstrated that on-site biological treatment of even a challenging oily waste such as spent forging fluid is technically feasible and cost effective. Moreover, the treatment system was easily assembled on site from readily available commercial components. Furthermore, and unexpectedly, the demonstration showed that the treatment system is easily modified to accommodate major changes in plant operations and still meet the treatment requirements. In general it should be possible to implement this technology at any site that has oily waste. The primary operating requirements are an SBR sized to provide 4-8 days of treatment that is equipped with a pH controller, aeration system, centrifugal pump to mechanically emulsify the oil, and a weir that captures oil that pools on the surface of the SBR. As a general rule of thumb, nutrients are added in proportion to the volume of oily wastewater being treated (Table 16) and maintain the target values for nitrogen and phosphorous at 200 ppm and 80 ppm respectively. In addition one pound of Novozyme Accelerator V which provides trace nutrients should be added to the SBR when the total volume of wastewater that has been treated and decanted is 40,000 gallons. Operation of the SBR should be tracked using the format shown in Table 17.

Table 16. Recommended nutrient required per 1000 gal of oily wastewater.

Nutrient	Amount Per 1000 gal of Fresh Wastewater
Yeast extract	0.5 pounds
NZ amine	0.2 pounds
Accelerator II	1 gallon

Table 17. Suggested format for recording daily operation and monitoring data.

Date	Time	SBR – CYCLE F- Fill R- React S - Settle D-Decant	NUTRIENTS					T	pH	DO
			Yeast Extract	NZ Amine	Accelerator II	Accelerator V	Fertilizer			

An unexpected problem was the presence of suspended solids in the wastewater discharged from the SBR after it was settled. Since the solids rapidly settled in the pilot studies, the original filtration system (an ultrafilter) was replaced with a tube filter. However, a 1-5 µ tube filter (the smallest available) removed little if any of the suspended solids. Ongoing experience with the system in Hawaii has shown that an ultrafilter is inappropriate, but suspended solids are easily removed by spiral wound microfilters in series with a 1-5 µ bag filter and the use of these units at SCAAP is recommended. At the completion of the Phase II testing, SCAAP switched to a water-based forge lubricant and this project was not funded to investigate its fate in the treatment system. However, SCAAP has used the values identified during Phase II testing (nutrient

concentrations, F/M ratio, biomass wasting) to successfully operate the system. In addition they replaced the tube filter with a membrane filter which has enabled them to reclaim the treated wastewater and use all of it for cooling various processes in the plant.

Preliminary testing of spent forging oil degradability demonstrated that on-site treatment was technically feasible. In addition, the economics of on-site treatment compared to off-site disposal was cost-effective (payback ~2 years) and would reduce (ideally eliminate) recurrent and expensive violations of the SCAAP discharge permit. However, two unanticipated problems arose after the system was installed that had a significant negative effect on treatment performance and had to be solved if the system was to perform as intended. The first problem was caused by the high viscosity and cohesiveness of the spent oil. While these properties were noted during the feasibility study and the system was designed to accommodate these characteristics, the requirements for handling this material in a full-scale system were not fully comprehended. The second problem was a result of how SCAAP managed the oil that collected in the trenches, a detail that only became evident after SCAAP reduced the volume of wastewater.

The first problem was solved by modifying the plumbing in the SBR so that the oil was kept suspended and emulsified. The second problem was more challenging and arose because the trenches under the forges were (unknown to us) used as gravity OWSs. As a result, the bulk of the oil remained in the trenches and SCAAP treated (ineffectively) only the lower, mostly water phase in their oily wastewater plant—a fact that did not become apparent until the system was installed and testing begin. Specifically, the incoming oil concentration (all of the oily wastewater, not just the lower, mostly water phase, was pumped to the biological treatment system) was at least an order of magnitude greater than the system was designed to treat (i.e., expected 4000 - 5000 ppm and actual >40,000 ppm). This problem was solved by converting SBR B to a gravity OWS and installing a skimmer to recover spent oil, which was sold to a recycler (a market that was previously not available). The lower water phase was pumped to the SBR A where residual oil was degraded. Subsequently, SCAAP added a membrane filter to remove particulates from the treated wastewater, and all of the reclaimed water is used for cooling.

In retrospect, the obvious lesson is to ensure that the characteristics of the waste stream at the source (not just from samples) and how it is actually managed are understood as thoroughly as circumstances permit. Spending more time observing and discussing how the wastewater was generated and managed might have led to a better understanding of these issues.

Simplicity and reliability of operation are also helped by dedicated microprocessors that are used to automate and monitor the treatment system. However, the industrial microprocessors that are most often used are expensive and require a high level of programming skill. The latter is particularly problematic when (not if) errors occur, components are upgraded, or changes are made in the treatment system, all of which require program changes. As an alternative, control systems (e.g., Opto22) that run on a laptop (rather than an expensive industrial microprocessor), are easier to program and provide a more intuitive interface that may be more appropriate for this and similar applications.

10.0 REFERENCES

A complete description of the site, installation, and results can be found in: Oily Sludge Biodetoxification: Final Report, S. Maga and F. Goetz, April 2011.

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APPENDIX A
POINTS OF CONTACT

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Mr. Tim Tuttle, P.E.	Scranton Army Ammunition Plant Army Ammunition Plant 156 Cedar Avenue Scranton, PA 18505-1138	Phone : (570) 340-1163 Fax: (570) 340-1189 E-mail: tim.tuttle@aco.pica.army.mil	Project and test site support
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Mr. Randall Jones	Wastewater Resources Inc. 9318 N. 95th Way Suite 102 Scottsdale, Arizona 85258	Phone: (480) 391-9939 Fax: (480) 391-0794 E-mail: rjones@h2oreuse.com	System source (vendor) and installation
Mr. Steve Christiansen	NAVFAC FEC Hawaii	Phone: (808) 474-0392 E-mail: steven.christiansen@navy.mil	Prototype system development support
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